Ecological conditions influencing the localization of egg-laying by females of the cockchafer (*Melolontha hippocastani* F.)

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ABSTRACT: We explored the ecological conditions, which influence the female *Melolontha hippocastani* F. in their selection of the locality for laying eggs. In the region of mass outbreak of *M. hippocastani* in the south-eastern part of the Czech Republic in selected experimental sample plots including 1 to 8 year-old forest plantations we explored the extent of losses caused by white grub feeding and the relation between the extent of the damage and the individual characteristics of the experimental plots. The relation between the extent of the damage and the method of establishment of the stands and degree of weed infestation at the time of swarming was evaluated statistically. The daily temperatures at the time of *M. hippocastani* swarming were recorded by means of automatic meteorological stations. A light trap was used to monitor the course of swarming.

Keywords: forest protection; *Melolontha hippocastani* F.; white grub feeding; losses in forest plantations

In the regions of mass outbreak the *Melolontha hippocastani* F. white grub feeding on roots causes considerable damage to plants of forest tree species, especially pine, oak, linden and others, sometimes destroying as much as 100%. The damage appears in 1 to 10 year-old forest plantations in the period when the 2nd and 3rd white grub instars are developing (Záruba 1956; Švestka, Kapitola 2004). In the Czech Republic at the present time *M. hippocastani* has gradated on ca 10,000 ha of forest soil and the area of destroyed forest plantations in the individual years ranges from ca 50 to 300 ha (Švestka 2006). That means that in the most seriously affected regions forest regeneration has been considerably hampered causing heavy economic losses amounting to several million CZK. Defoliation caused by maturation feeding of beetles at the beginning of the vegetation period is usually not very serious for forest management. The only exception is when they feed on young one or two-year-old broadleaved plantings. On the other hand white grub feeding in forest plantations followed by dieback of tree causes serious damage to forest management and may even restrict forest regeneration.

Possibilities of protection in the period of swarming of *M. hippocastani* adults are very limited because of environment protection in the localities, which are part of protected areas (Natura 2000, avian territory). The effectiveness of an intervention using insecticides is also limited because of the long period of swarming (several weeks); it is difficult to reduce the cockchafer population with one single application of effective chemical insecticide. The bio-preparations tested so far have usually not achieved the required results.

Using a soil insecticide, which is usually applied to the roots at the time of planting, appears to be a promising measure against the white grub. With this method of protection accurate prognosis when selecting the endangered localities is very important; the application of the soil insecticide must be

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targeted and sufficiently effective and economical. It is therefore important to obtain as much information as possible about the circumstances and effects, which influence the *M. hippocastani* female when selecting a locality to lay eggs.

Forest regeneration is affected by white grub, which develops in forest plantations younger than ca 10 years, namely in one to two-year-old stands. Most endangered are plantations established two years before the main swarming period; that means at the time when the newly planted plants are exposed to feeding of white grub of the 2nd and 3rd instars in two vegetation periods. Feeding of white grub developing in older stands does not cause tree dieback. In terms of forest protection it is therefore important to explore, which climate, ecological and economic effects may affect egg-laying of the females in the endangered localities, or which economic measures would discourage the females to lay eggs in the young forest plantations, or reduce it.

The objective of the study and the studied region

The objective of the study was to evaluate the extent of damage caused by white grub feeding in a selected set of sample plots with forest plantations aged 1 to 8 years in the period until the next swarming; basing on the correlation between the extent of the damage and the individual characteristics of the sample plots to deduce, which factors influenced the *M. hippocastani* females in their selection of the locality for laying the eggs.

Experimental investigations were conducted in the Vracov locality (coordinates 54°29', 36°62') in the Forest District Strážnice, altitude 193 m. In this district 62.7 ha of young forest stands were destroyed by white grub in 1999–2002 during the *M. hippocastani* developmental cycle; in the following developmental cycle in 2003–2006 it was 86.5 ha. The Vracov locality lies in south-east Moravia where the long-term average air temperature is 9.3°C and the annual sum of precipitation ranges around 450 mm. It is one of the warmest regions in the Czech Republic. A strong tribe of *M. hippocastani* with a 4-year developmental cycle is located in the Vracov locality. The last two heavy swarms appeared in 2003 (Švestka 2006) and in 2007.

MATERIAL AND METHODS

A light trap with a HQL 125 W discharge lamp was used to control the swarming. The numbers of trapped cockchafers and the sex ratio were recorded on individual days. The insects swarmed from 20 April to 2 June 2003.

In 2003, at the time of mass swarming of *M. hippocastani* in the Vracov locality, we recorded and evaluated the daily maximal, minimal and average temperatures using an automatic meteorological station of the 431 B type.

Research activities were launched in 2004, one year after mass swarming of the *M. hippocastani* adults. In the first stage we selected 30 sample plots, i.e. forest plantations, and in the two following years we monitored the course and extent of damage on plants caused by cockchafer feeding. In the individual sample plots we recorded the age of the plants, tree species, method of establishment (full-area preparation, ploughing, repair planting), presence of broadleaved species in the neighbourhood, degree of weed infestation at the time of swarming and the final extent of plant losses after the end of white grub development in the second half of 2006 (Table 1).

The plantation in the region was established using two methods; full-area soil preparation and ploughing of the forested area. Full-area preparation consisted of pulling out the stumps, part of which were placed into a prepared hole and covered with earth and part was heaped into a mound across the forested area. The whole area was ploughed and evened out so that the tree plants were planted out in an area completely free of weeds. Using the other method, i.e. ploughing, the stumps remained on the forested area and furrows were ploughed across the area, 1.4 m spacing. The plants of the woody species were planted into the ploughed up furrows; the original weeds between the rows were preserved and they very quickly grew back into the furrows. To a lesser extent the plantation was established using repair planting in places where white grub feeding had destroyed the plants; subsequently the open places were planted out. In recent years we see efforts to apply natural seeding, i.e. of plants, which grow from seeds carried over to the open space from the neighbouring stands.

The correlation between the extent of the damage and method of plantation establishment and degree of weed infestation at the time of swarming was evaluated statistically using variance analysis (ANOVA). Considering that the values of the individual degrees of factors were very unbalanced and no normality and homoscedasticity of the individual sets was proved (tested by Shapiro-Wilks normality test and Bartlett test of homoscedasticity), we used the non-parametric Kruskal-Wallis test and subsequent test of multiple comparisons

Table 1. Survey of sample plots

Stand No.	Area (ha)	Age 2003	Tree species	Losses-reduced area (%)	Method of establishment	Broadleaves in neighbourhood	Spraying 2003	Weed infestation 2003 (%)
220A12	0.9	2	Pinus	100	ploughing	from all sides – B,C,Q,F	yes	100
220A0	1.5	2	Pinus	100	ploughing	from all sides – F,Q,T,B	yes	100
260D12	2	1 to 7	Pinus	40	ploughing	none	no	70
261A11	1.2	1	*Pinus, Betula*	20	full-area prep.	from one side *Robinia*	no	20
262B12	1.5	1 to 8	*Pinus*	20	repair planting	from one side – Q,B,F,R	yes	70
263A10-1	1.7	4	*Pinus*	0	full-area prep.	from one side – F,Q	yes	0
263A10-2	1.7	4	*Pinus*	80	ploughing	from one side – Q,C,F	yes	100
256C10-1	2	7	*Pinus*	60	ploughing	from one side – Q,C,F	yes	100
256C10-2	2	8	*Pinus*	5	full-area prep.	form one side – F,T,C	yes	0
256B10	2	8	*Pinus*	0	full-area prep.	none	no	0
247A1	0.3	1 to 4	*Pinus*	10	repair planting	from one side – Q,A	no	0
248A11	0.9	3	*Pinus*	0	full-area prep.	none	no	0
247A11	1.3	2	*Pinus*	60	ploughing	none	no	100
247C10	2	1	*Pinus*	50	ploughing	none	no	100
249B9	1	3	*Pinus*	0	full-area prep.	none	no	0
249E	1	3	*Pinus*	0	full-area prep.	none	no	0
248B10	1.4	6	*Pinus, Tilia*	30	repair planting	none	no	30
248C10	1.4	1	*Pinus*	90	ploughing	none	no	100
248A11	1.5	8	*Pinus*	0	full-area prep.	none	no	0
252D10	1.3	5	*Pinus*	0	full-area prep.	from two sides *Quercus*	no	0
252C10	1.8	4	*Pinus, Tilia*	5	full-area prep.	*Robinia* in undergrowth	no	0
252B10	1.6	4	*Pinus, Tilia*	5	full-area prep.	*Robinia* in undergrowth	no	0
253B10	1.3	4	*Pinus, Tilia*	20	ploughing	*Robinia* in undergrowth	yes	50
224C11	3	4	*Pinus*	40	ploughing	*Robinia* in undergrowth	yes	100
223D11-1	2	9	*Pinus*	10	ploughing	none	yes	100
216C10	0.7	3	*Tilia, Pinus*	10	ploughing	none	yes	100
223D11-2	1.8	7	*Pinus*	0	natural seeding	from one side – Q,B	yes	0
220B11	1	2	*Pinus*	5	ploughing	none	no	50
249A11	0.4	2	*Pinus*	30	ploughing	none	no	100
223C1	0.8	10	*Pinus*	40	ploughing	none	no	80

Q – *Quercus*, B – *Betula*, F – *Fagus*, R – *Robinia*, C – *Carpinus*, T – *Tilia*, A – *Alnus* by means of the Statistica 7.0 statistical programme (StatSoft, Inc. 2006).

RESULTS AND DISCUSSION

From the results of controls of cockchafer swarming in 2003 (Fig. 1) it follows that the beetles emerged from 16 April to 2 June when 19,510 cockchafers were trapped in the light trap, of which 12,054 were males and 7,456 females. Heavy intensive swarming was seen between 28 April and 12 May when 18,062 cockchafers were trapped, i.e. 92.58% of the total number of the entire period of swarming; in this time interval intensive egg laying into the soil could be assumed.

Basing on records of daily temperatures measured using the automatic meteorological station (Fig. 2) the average temperature in May 2003 was 17.4°C and during the 15 days of intensive peak swarming from 28 April to 12 May it was 18.2°C; in 4 days of this period the maximal temperature exceeded 30°C.

When we compare the temperatures in the Vracov locality in May 2003 with the 10-year average May temperature (Table 2 – data of the Hydrometeorological Institute, Strážnice, 176 m a.s.l.) it is obvious that the average temperature in May 2003 was by 2.3°C higher than the 10-year average. During the 5 days from 6 to 10 May 2003, i.e. in the period of the absolute peak of swarming, when the females probably laid eggs, tropical weather prevailed and the average temperature was 21°C, i.e. 6.6°C above the 10-year average.

Basing on evaluations of the extent of damage on plants depending on their age we see that the one and two-year old plantations were damaged most frequently and most extensively, although the damage was not negligible in older plantations as much as 10 years old either. If we take the individual species then damaged was almost exclusively pine and is due to the fact that the proportion of pine in reforestation in the region is ca 90%.

The effect of the method of establishment of the plantation on the damage of plants showed a statistically significant difference between losses in full-area prepared areas and ploughed areas, in favour of full-area preparation where 0 to 20% of the plants were damaged, but mostly not exceeding 5%. After ploughing the plant losses reached 0 to 100%; on the larger part of the area the losses exceeded 50% (Fig. 3). We did not have enough data to carry out statistical evaluations of the losses after repair planting and natural seeding.

Weed infestation is also closely connected with the method of plantation establishment. A statistically significant difference was observed between the zero and 100% degree of weed infestation, whereas for evaluations of the medium level of weed infestation these data were too variable (Fig. 4).

Broadleaved trees in the neighbourhood of the sample plots were sources of maturation feeding of the beetles and a place where they gathered. It is a factor, which contributes to the selection of places in the neighbourhood for laying eggs; however from our present evaluations we cannot determine

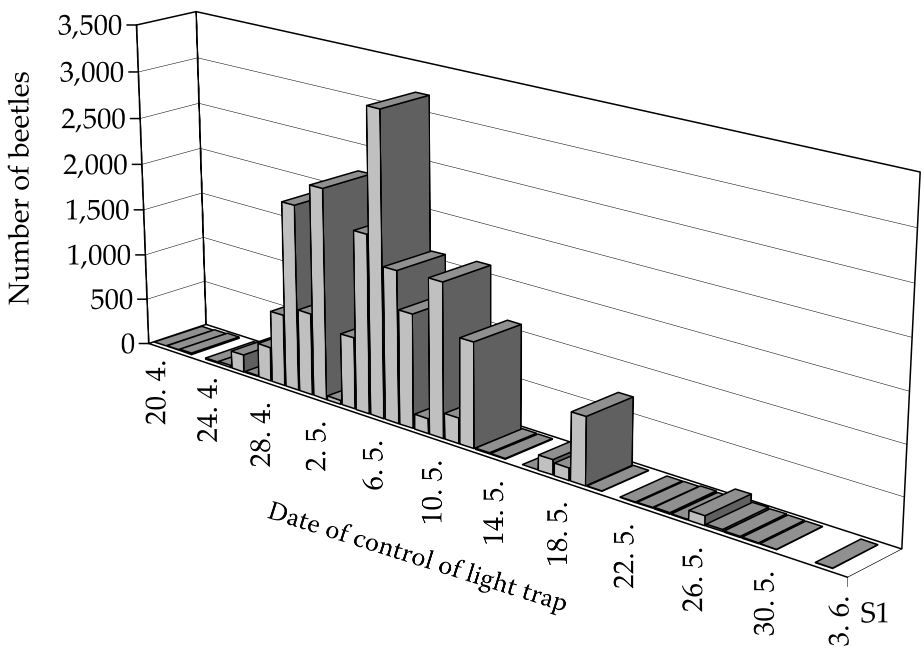


Fig. 1. Swarming of *Melolontha hippocastani* F. in 2003 in the Vracov locality

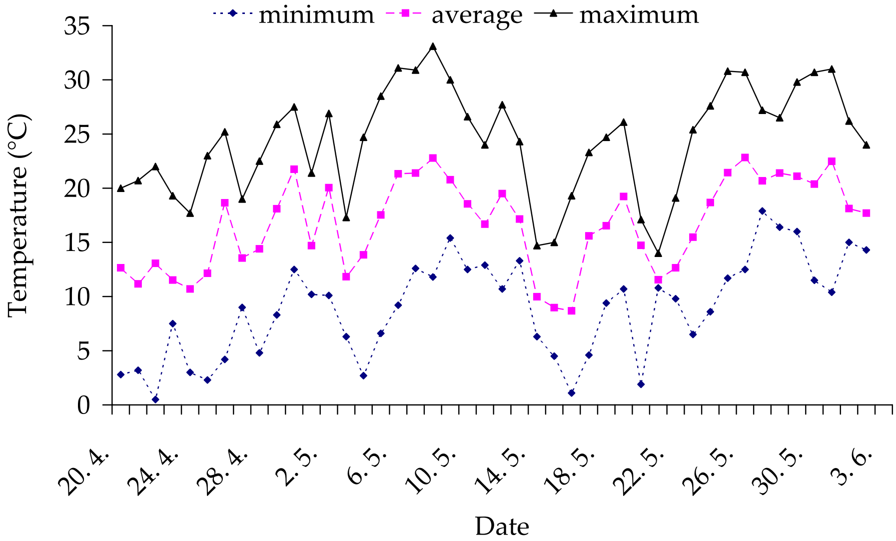


Fig. 2. Daily temperatures at the time of *Melontha hippocastani* F. swarming in 2003 in the Vracov locality

a definite dependence. Likewise data on the effect of aerial interventions in 2003 on an area of 508 ha against the beetles at the time of swarming were not evincible.

In 2003 when the *M. hippocastani* females laid their eggs the temperatures were above-average. We must take this fact into account when we assess the loss of plants in the respective sample plots and when we define the correlation between the extent of the damage and the individual ecological characteristics. It would be worthwhile to compare these findings with data obtained in the following developmental period of *M. hippocastani,* i.e. under different meteorological conditions, to be able to specify the effect of the individual ecological factors.

Kratochvíl et al. (1953) summarized information and data on the egg-laying of female cockchafers. How deeply they lay the eggs depends on the looseness and type of soil. The eggs are most frequently laid in clusters of 10 to 36 eggs in a depth of ca 10 to 30 cm. Flerov et al. (1954) reported that the eggs are laid in small piles of not more than 20 eggs. After the eggs are laid the females crawl out to the surface and return to the second maturation feeding and when it is finished they lay eggs again. Some females fly to their third maturation feeding and then lay eggs for the third time. Under the same conditions *Melolontha melolontha* L. females lay the eggs deeper in the soil than those of *M. hippocastani.* The development of the eggs from the time of their laying until the larvae hatch depends on the temperature and humidity of the soil and usually lasts 40 to 50 days. The development of white grub is dependent on the climate conditions

Table 2. Average temperatures in May in 1997 to 2006 – Strážnice

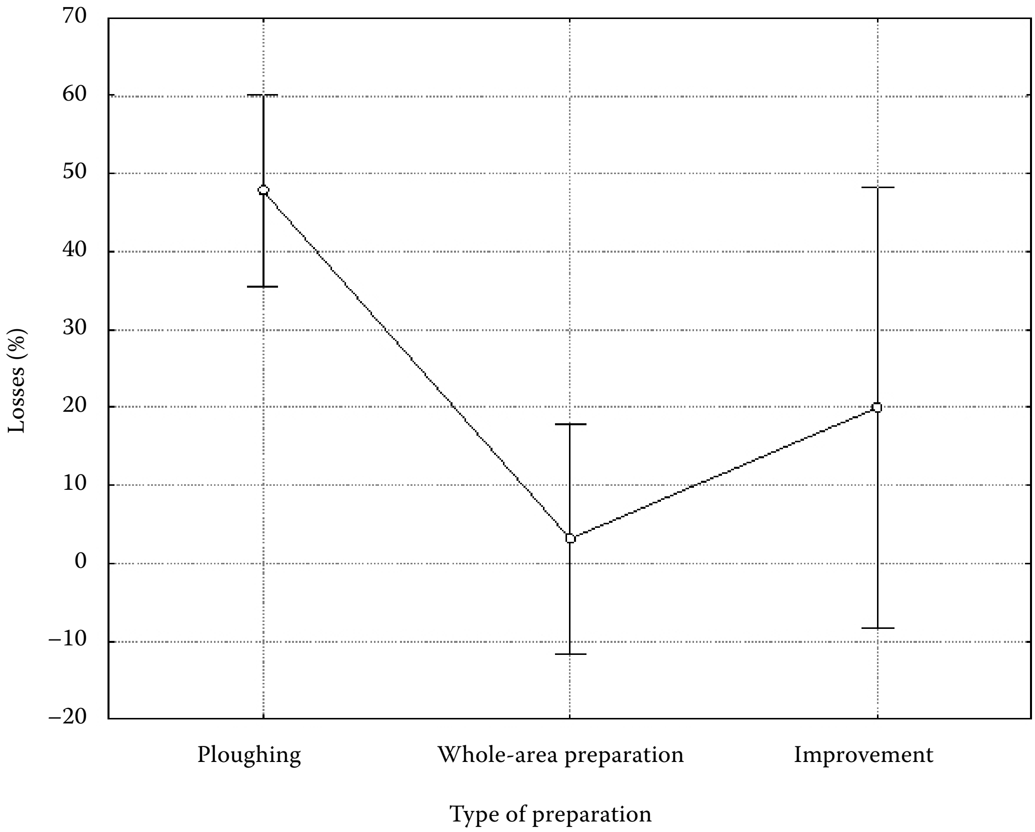
Year	Days						
	1–5	6–10	11–15	16–20	21–25	26–31	1–31
1997	15.1	13.1	20.4	21.2	13.7	10.9	15.6
1998	12.7	17.4	17.4	13.9	12.3	19.6	15.7
1999	14.2	13.7	14.0	13.3	16.1	22.0	15.7
2000	14.7	17.6	15.8	14.9	14.2	16.4	15.6
2001	18.2	13.3	13.5	14.7	14.1	17.0	15.2
2002	19.7	16.4	16.5	17.5	18.5	15.7	17.3
2003	15.0	19.6	13.5	14.8	14.8	19.6	16.3
2004	16.5	10.9	11.2	11.9	10.0	12.9	12.3
2005	15.7	8.3	11.0	11.4	15.1	19.6	13.5
2006	11.8	14.1	14.3	16.5	16.2	12.3	14.1
Average	15.4	14.4	14.8	15.0	14.5	16.6	15.1

(N – ploughing, C – whole-area preparation, V – improvement) (H is the test criterion) P = 0.001

	Code	Number of valid	Sum of sequences
N	101	16	344.500
C	102	11	72.500
V	103	3	48.000

Kruskal-Wallis test: H (2, N = 30) =19.14298, P = 0.0001

Preparation; MNC means
Current effect: F (2, 27) = 11.593, P = 0.00023
Decompositon of effective hypothesis
Vertical columns indicate 0.95 intervals of reliability



The hypothesis that the effect of soil preparation on losses during forestation has no effect was rejected.

	N R: 21.531	C R: 6.5909	V R: 16.000
N		0.000044	0.952883
C	0.000044		0.302437
V	0.953883	0.302437	

Test of multiple comparisons: as shown in the graph, the difference between ploughing and whole-area preparation is significant.

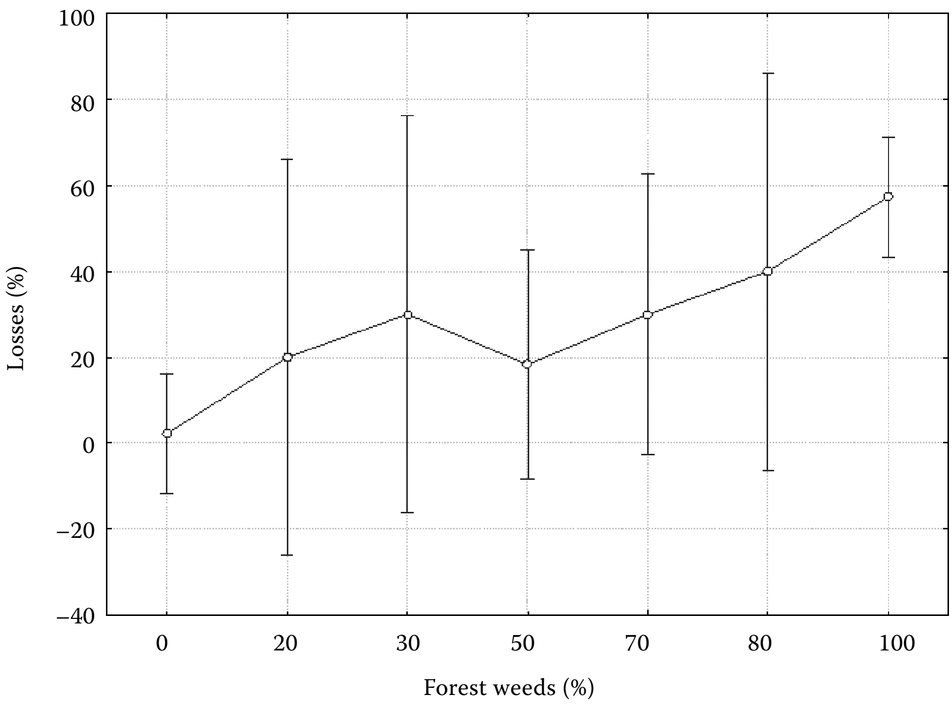
Fig. 3. Comparison of losses in terms of soil preparation

of the region; in nature the cycle of cockchafer generations takes 3 to 5 years. Only *M. hippocastani* are known to have a 5-year cycle, i.e. in the more northern regions. In the 3-year developmental cycle the first moulting takes place as soon as in the year of hatching and already in the advanced second stage the larvae winter. In the 4-year developmental cycle the first moulting of larvae does not occur until after wintering, i.e. in June to July of the second year of their development. The length of the developmental cycle is affected particularly by the temperature during the 1st and 2nd larval stage. In the soil the white grub moves horizontally when searching for food and the depth depends on the

Code	Number of valid	Sum of sequences
0	11	69.500
20	1	16.000
30	1	19.000
50	3	44.500
70	2	38.000
80	1	22.000
100	11	256.000

Kruskal-Wallis test: H (6, N = 30) = 21.99181, P = 0.0012

Forest weeds; MNC means
Current effect: F (6, 23) = 5.7547, P = 0.00089
Decompositon of effective hypothesis
Vertical columns indicate 0.95 intervals of reliability



The hypothesis that weed infestation has no effect on losses was rejected.

Due to the great variability of the data only the significant difference between zero and full weed infestation can be confirmed.

Fig. 4. Comparison of losses in terms of the rate of weed infestation

soil humidity and temperature; if the soil is dry and cold the white grub hide deeper in the soil. The usual depth for wintering is 30 to 60 cm, sometimes even 150 cm; during feeding the white grub move in a depth of 5 to 20 cm. Horizontal movement in search for food depends on the temperature and type of soil. During their development the white grub may move to an average distance of 70 to 150 cm, maximally to a distance of 3 to 4.5 m. The most serious damage is caused by white grub of the 2nd and namely 3rd stage feeding roots ca 5 mm deep and gnawing the stronger roots. White grub is largely omnivorous, but in our experience it is obvious that in the felled areas it prefers roots of plants, particularly pine, oak, linden and in forest nurseries also spruce plants. White grub does not attack willow, poplar or alder. A full-grown white grub of the 3rd stage pupates in July to August in a depth of 30 to 40 cm or even more.

Opinions on how the female *M. hippocastani* choose the place for laying the eggs differ. For instance Flerov et al. (1954) discovered that females prefer places shaded by tree crowns, but they avoid over-shading and so they do not fly into very dense stands. On the other hand, in colder northern locations they find optimal conditions for development on open areas without trees, in forest glades and clearings. However in all the areas the cockchafer finds optimal conditions in pine saplings where it concentrates. On the other hand Záruba (1956) reported that *M. hippocastani* appeared mostly in open broken oak forests and free-growing broadleaved young growth and that they damaged the invaded trees usually over the entire space of open stands. Irregular infestation of forest plantations is influenced by the uneven distance of the forested area from the feeding places of the cockchafers as well as the soil properties and different micro-climate conditions. The female's choice of the place for laying the eggs is based on the micro-climate conditions and soil properties. They avoid places shaded by the surrounding stand and by individual trees. They seek out weed-free places in forest tree nurseries and in loosened soil.

According to Flerov et al. (1954) in the more southern localities on light sandy soils the *M. hippocastani* female lays eggs in relatively dense stands and in heavy soil in more open stands. In the more northern localities they gradually choose more open localities, for instance forested clearings, and in the northernmost part of their distribution they lay eggs in open sun-warmed clearings.

The general findings of Flerov et al. (1954) and Záruba (1956) that the choice of the locality for the laying of eggs is influenced by the momentary temperature were confirmed. Under high temperatures the females choose areas shaded by tree crowns or weeds and in cold weather they prefer more open localities. Depending on the temperature at the time of egg-laying the females look for localities, which provide optimal conditions for the development of the new population; these places may be variously thick stands and clearings with plants of various ages and with a different level of weed infestation. The degree of white grub infestation of forest plantations is also dependent on the distance from the cockchafers' feeding places and on soil and microclimate conditions.

CONCLUSION

In the locality there is one cockchafer tribe, which does not form sub-populations in the years between the main swarmings and in the individual years the damage is caused by white grub of the same instar.

In the period of peak swarming in the emergence year 2003 and when the *M. hippocastani* females laid eggs, it was very warm in the Vracov locality with above-average temperatures.

Results of control of the damaged plants confirmed that plant losses on the areas forested after full-area preparation with no weeds at the time of swarming were considerably lower than on the ploughed areas heavily weeded between the rows.

The results of statistical evaluations confirmed that when choosing the place to lay their eggs the females preferred localities shaded by the forest stand or at least by weeds.

The effect of broadleaved trees as a source of food during maturation feeding of adults on the amount of damaged plants in the neighbouring plantations was not positively confirmed.

Likewise the effect of aerial preventive intervention against the beetles conducted in 2003 on the amount of damages plants was not demonstrable. Comparisons of the population density in 2003 and 2007 will be able on the basis of results of the control of swarming in the light trap in both years.

In terms of preventive protection against plant losses caused by white grub it appears that appropriate is full-area soil preparation. However, the results achieved in 2003–2006 must be correlated with concrete meteorological conditions at the time of egg-laying in 2003 and compared with results of similar investigations conducted in the period 2007–2010.

We can wrap-up by saying that the degree of damage of the plantation depends on the numbers of white grub and on the age and spacing of the plants. The larger the number of high-quality plants with a well developed root system is used for reforestation, the more likely is successful regeneration. The tree species, e.g. pine, are capable of regeneration after the root system is damaged. New roots grow above the damaged part, which can substitute the destroyed roots. Regeneration of the damaged roots is dependent on the degree of damage and on soil humidity. However, with mass outbreak of white grub we see that also grown up plants succumb, or if the root system is damaged seriously they die in the following year.

Successful regeneration is also influenced by correct technology of planting and by the site conditions, as they considerably affect the regeneration ability of the plants.

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Ekologické podmínky ovlivňující lokalizaci kladení vajíček samičkami chrousta maďalového *Melolontha hippocastani* F.

ABSTRAKT: Byly studovány ekologické podmínky ovlivňující samice *Melolontha hippocastani* F. při výběru lokality pro kladení vajíček. V oblasti kalamitního přemnožení *M. hippocastani* na jihovýchodě České republiky byl ve vybraném souboru zkusných ploch, zahrnujícím lesní kultury ve věku jednoho až osmi let, hodnocen rozsah ztrát způsobených žírem ponrav a posuzován vztah mezi rozsahem ztrát a jednotlivými charakteristikami pokusných ploch. Vztah mezi rozsahem ztrát a způsobem založení kultury a stupněm zabuřenění v době rojení byl vyhodnocen statisticky. Denní teploty v období rojení *M. hippocastani* byly zaznamenány pomocí automatické meteostanice. Průběh rojení byl kontrolován světelným lapačem.

Klíčová slova: ochrana lesa; *Melolontha hippocastani* F.; žír ponrav; ztráty v lesních kulturách

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